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METHOD AND DEVICE FOR SCANNING OBJECTS

(0001) The present invention relates to the precharacterizing clauses of the independent claims. The present invention thus relates to the three-dimensional scanning of objects.

(0002) The 3-D shape of objects is frequently measured using strip triangulation methods. In this case, the object or the scene is generally illuminated at an high incidence angle, for example between 30° and 60°. However, this leads to disturbing shadows on the object.

(0003) Discontinuous surfaces often represent a problem in optical 3D measurement. For example, relatively large steps in the surface of the object can lead to infringement of the sampling theorem. This is overcome by using the Gray coding method, in which a sequence of binary images is projected. One example is the COMET-500 system from Steinbichler Optotechnik GmbH. In order to achieve a large depth of focusing when measuring deep objects, heavy masking is generally used in all known methods, both for the illumination and for the imaging of the object surface. GFM, at D-14513 Teltow, offer digital light projection based on illuminated micromirrors, digital micromirror devices. Grating images with a repetition frequency of about 10 Hz can be produced and recorded. However, this frequency is still not sufficient for high-speed image recording.

(0004) Patent Specification WO 92/14118 describes a 3D measurement arrangement which is referred to as being "confocal" and which evaluates the contrast in a strip pattern projected onto the object surface. In this case, both the illumination objective and the imaging objective, or a common objective, are each focused onto the same plane within the volume of the object. However, there is no capability for achieving high accuracy for object distances in the order of

tenths of meters and meters.

(0005) Apparatus for 3D scanning of objects are known, for example, from DE 197 49 974, from the article "Optical 3D-measurement using structured light" by R. Kowarsid, J. Gerber, G. Notni, W. Schreiber and P. Kühmstedt in "Technisches Messen" [Technical Measurement], Vol. 62, 1995, pages 321-329. Furthermore, the article "Phase-shifting grating projection moire topography" by Y.-B. Choi and S.-W. Kim in Opt. Eng. 37 (3) 1995-1010 deals with the scanning of three-dimensional objects using shifted shadow gratings. In this case, a signal is evaluated as a function of the movement of a shadow grating. It should be mentioned that the expression "shadow grating" is used to clarify the fact that the present invention does not generally relate to the diffraction characteristics of a grating. This is also true in the following text, unless mentioned to the contrary.

(0006) While, in principle, there are various possible ways to scan a three-dimensional object, problems occur when the aim is to scan a large three-dimensional object quickly and precisely.

(0007) The aim of the present invention is to provide a novel feature for industrial application.

(0008) The aim is achieved by the features in the independent claims.

(0009) In a first refinement, the invention thus proposes an apparatus for three-dimensional object recording having at least two imaging systems, which have imaging optics facing the object, with at least one being in the form of an observation system for object observation, and at least one of them having an elementary means which move in front of the imaging optics and whose elementary image is moved on an image point line through the object area, with the invention providing that the elementary means are elementary means which also move with a lateral component with respect to the optical

axis of the imaging optics, as a result of which the image point line is inclined with respect to the optical axis of the imaging optics, and the observation system is arranged for observation along the image point line.

(0010) A first major aspect of the invention is thus that two separate optical systems are provided having elementary means which move, with the observation being carried out, using one of the two systems, along the image point line. In this case, the elementary means may be moved with respect to one another.

(0011) A stereo camera can be formed in this way. In this case, the imaging systems represent observation systems. It is possible to use detector arrays, in particular CCD arrays, which are moved synchronously, for example by piezo control means. The signals obtained from these detectors can be selected in a preferred manner by recording when a specific object region produces a specific signal response. In the case of light-emitting objects, for example objects which are illuminated with a bright light or objects which emit light themselves, this is the situation when a particularly large signal is recorded from the observed object point in the first and second arrays.

(0012) However, it is not absolutely essential for the apparatus according to the invention to be equipped with a stereo objective, as a 3D camera. Alternatively, a scanner can be provided, in which one of the imaging systems is an illumination system. This illumination system will preferably illuminate the object by means of a row of separate light-emitting elements, which provide the moving elementary means. Alternatively, it is possible to simulate a row of light-emitting areas, which simulate the elementary means movement as a virtual movement, that is to say they are excited in accordance with a predetermined pattern. Generally, the observation system will comprise a large number of observation

elements, in which case each observation element may have an associated object region. One advantage of the arrangement according to the invention is then, in particular, that the signals can be evaluated by recording the surface only when a specific signal, such as a signal maximum, is recorded for a specific pixel of the array. The pupil of the observation system is preferably arranged in the focal plane of the imaging optics, and/or at least essentially in this focal plane.

(0013) The invention thus achieves the object of testing the 3-D shape of the surface of technical and natural surfaces of objects in space and scenes, preferably with dimensions in the region above one millimeter. The invention thus allows rapid recording and testing of the 3-D shape of bodies in scenes with a large depth extent. Complete scenes can be recorded realistically.

(0014) Furthermore, the required light power for illumination of object surfaces in a scene is greatly reduced in some cases. This is due to the fact that object recording takes place when a particularly large amount of light reaches the detector. A further improvement is the considerable increase in the evaluation rate for 3D recording. It is thus technically possible to provide the 3D point cloud of the object or of the scene in time with a video.

(0015) Protection is also claimed for the method according to the independent claims. In a first method for 3D recording of at least one object surface in at least one scene, at least one electromagnetic radiation source is arranged and is formed by means of at least one structured array as at least one structured-light-emitting array having at least two surface elements. In this case, at least one surface element emits light. The structured-light-emitting array may also be regarded as a transmitter array, and the light-emitting surface elements may be regarded as transmitted

elements in this transmitter array. Furthermore, the structured-light-emitting array may also be an array of controllable micro light sources, for example micro light-emitting diodes. However, the radiation source may also be arranged, as an unstructured radiation source, in front of a structured array, which may be a transmission or a reflection grating. In any case, the light-emitting regions of the structured-light-emitting array are light-emitting surface elements in a light intensity distribution in the structured-light-emitting array. Furthermore, at least one illumination beam path having at least one illumination objective is arranged, and has at least one associated structured-light-emitting array. Imaging is thus achieved, and the object surfaces can be illuminated in a structured manner. Furthermore, at least one imaging beam path is arranged for the imaging of elements of the object surface, and at least one receiver array having at least two elements is arranged, and at least one imaging objective is arranged, which has an associated receiver array. In this case, elements in the receiver array detect radiation from elements of the illuminated object surface during the recording process. Furthermore, images are also always formed with a geometric-optical sharp-image volume in the object area, which corresponds to the scene space, from elements of the receiver array by means of the imaging objective. At least one light-emitting surface element of the structured-light-emitting array can be moved. The use of the illumination objective for imaging of the light-emitting surface element or elements results in an image of at least one light-emitting surface element being formed in the object area with a geometric-optical sharp-image volume. The receiver array may be a target with a coating which is sensitized to X-ray, UV, VIS or IR radiation and is read using a raster pattern. Furthermore, the receiver array in an arrangement for 3D recording may be a CCD

matrix camera. This allows optimum image recording for standard tasks with a good signal-to-noise ratio. In addition, the receiver array may be a CMOS matrix camera. Selective access to pixels thus makes it possible to track moving elements of the object surface in space.

(0016) The detection of radiation from the elements of the object surface by means of the elements in the receiver array takes place in a time period Δt_B in which the movement of at least one light-emitting surface element of the structured-light-emitting array is also carried out, with at least one signal value being obtained in each case. In this case, an at least approximately predetermined movement is carried out within the time period Δt_B, at least with one light-emitting surface element of the structured-light-emitting array - including any predetermined optical movement of it resulting from a geometric-optical path length change - and hence at least one light-emitting surface element emits radiation at at least two different locations at different times. In this case, the sharp-image volume of at least one image of at least one light-emitting surface element of the at least one structured-light-emitting array, with this sharp-image volume being formed in the object area, and the sharp-image volume of at least one image of at least one element in the receiver array, with this sharp-image volume likewise being formed in the object area, and at least one element of the at least one object surface are made to coincide at least approximately once on the basis of the predetermined movement that is carried out on at least one light-emitting surface element of the structured-light-emitting array with at least one movement component parallel to the optical axis of the illumination objective. The coincidence of the sharp-image volume of an image of a light-emitting surface element of the structured-light-emitting array and of the sharp-image volume of an image of an element in the receiver array and of at

least one element of the at least one object surface is thus produced, at least approximately and at least once, in the object area. When coincidence occurs, at least that element of the receiver array which is involved in this coincidence experiences irradiation which varies with time, at least once, in comparison to the situation where no coincidence occurs, and this element in the receiver array thus detects a changed signal at least once.

(0017) A light-emitting surface element may be linked in a fixed manner to a structure of a body, for example to a transparency maximum on a moveable transmission grating in conjunction with a radiation source. For the movement process, the positions of the light-emitting surface elements of the structured-light-emitting array, and the positions of the images of the light-emitting surface elements are determined in the object area using the Newton imaging equation from the position of the illumination objective in the 3D recording arrangement and from the focal length f_B of the illumination objective, and are realized, provided the approximations associated with this are acceptable. The movement is in this case preferably carried out at a constant speed.

(0018) In order to achieve a large depth of focus for the imaging of object surfaces in a scene for the method for 3D recording, the locations of specific relative light intensity of the structured-light-emitting surface, and hence also the locations of local extremes of the light intensity, are moved in the array area. The structured-light-emitting array may be an electronically controllable, structured-light-emitting array, for example an LCD with a radiation source arranged in front of it, which radiation source is moved in a straight line by means of a movement system. In the object area, these paths may be regarded as tracks of light points that are imaged successively, for example as the shifted extremes of the light intensity when a line grating is

illuminated at the transparency maximum, or the track of an image of an illuminated gap. The tracks of the light points can be observed on an object surface if the image of a light point and the observed point of the object surface coincide at least approximately. Lateral migration of the image of the light point can be observed by means of the triangulation effect during the movement of the image of a light-emitting surface element and of the image, which coincides with this, of an element in the receiver array. The offset from the original position increases as the difference between the illuminated region of the object surface and the current coincidence point of the two images increases, with the element in the receiver array detecting an increasingly unfocused image of the light-emitting surface element.

(0019) In a predetermined movement process of the structured-light-emitting array in a movement direction with a component in the z_A direction, this method allows a clear statement to be made on the presence of an element of the object surface at a predetermined location in the object area. In this case, the magnitude in the z_A direction is chosen such that the focused area migrates gradually through the object area from a close region to a far region by means of a predetermined, controlled movement of the light-emitting surface elements of the structured-light-emitting array. This method is carried out with all the light-emitting surface elements of the structured-light-emitting array, and with all the elements in the receiver array for all the elements of the object surfaces in the recording volume of the 3D recording arrangement. By multiple detection and reading during the movement process of at least one element of the receiver array, interpolation can be carried out to improve the accuracy of the determination of the location of a recorded element of the object surface. The aperture stop of the imaging objective can in this case preferably be made small,

for example the relative aperture may be 1:22, so that the sharp-image volume of the image of the elements in the receiver array has a large amount of depth. In contrast, the illumination objective may have a comparatively large relative aperture. For example, the relative aperture may be 1:2. The sharp-image volume can thus have a shallow depth. During the predetermined movement of a light-emitting surface element in the array area, the sharp-image volume in the situation being described here for each image of a light-emitting surface element in each case moves in the sharp-image volume of each image of an element in the receiver array. An element of the object surface may thus permanently be located in the sharp-image volume of an image of a receiver element. However, this element of the object surface is illuminated in a structured manner only if the sharp-image volume of the image of a light-emitting surface element coincides with an element of the object surface. A signal profile with a relative maximum of the time of coincidence can thus be detected by the element which is read a number of times - during the predetermined movement of a light-emitting surface element - of a receiver array. The predetermined movement of the light-emitting surface elements can be controlled electronically. In addition, the optical path length in the area in front of the receiver array can be changed by electronic control.

(0020) Furthermore, a method for 3D recording of object surfaces in a scene is proposed, in which the light-emitting surface elements are each moved on their own movement path relative to the illumination objective preferably in the time intervals Δt_i for the detection of light. In this case, the light-emitting surface elements preferably have a relative light intensity, which is predetermined to be at least approximately constant, at least at a time t_i within a time interval Δt_i, in a light intensity distribution. Furthermore, the light-emitting surface elements are each positioned on a

B-path BS_{Aj} with the B-paths BS_{Aj} representing the nominal locations for the light-emitting surface elements at a time t_i within the time interval Δt_i. The images of these B-paths BS_{Aj} are formed in the object area by imaging by means of at least one illumination objective, preferably to form a path locus SB_1 with a convergence point K_1. In this case, the convergence point K_1 is at least at a distance $d_{K1\ min}$ from the optical axis of the illumination objective of the 16th part of the distance d of the pupil center PZ_{OB} of the illumination objective from the pupil center of the imaging objective when it is furthest away. The depth sensitivity is accordingly low. The maximum distance $d_{K1\ max}$ is 16 times this. The value $d_{K1} = d$ is preferably used. At least in a time period Δt_B during the movement process of the light-emitting surface elements, one, and only one, image of a receiver element and one, and only one, image of a light-emitting surface element are in each case positioned in the object area, at least approximately jointly on the image of a B-path BS_{Aj}, at least at a single time t_i within each time interval Δt_i for detection. Thus, at least at this time t_i, a pair is in each case formed in the object area from the image of a receiver element and the image of a light-emitting surface element, and such pairs are thus produced in the object area, and are moved through the object area. In this case, sharp-image volumes of images of the light-emitting surface elements coincide with surface elements of the object surface at least once during the movement process. A current coincidence point is thus formed at this time t_i at the location of these pairs at the centroid of the current section volume of the sharp-image volume of the two images. The elements of the received array preferably detect a signal profile having at least one relative extreme of the signal magnitude in the time interval Δt_i of coincidence. During the movement process, the positions of the light-

emitting surface elements of the structured-light-emitting arrays and the position of the elements in the receiver array are always determined, and they are implemented, from the position of the illumination objective and from the position of the imaging objective in the 3D recording arrangement, and from the focal length f_B of the illumination objective and the focal length f_A of the imaging objective. Thus, in the object area, both the light-emitting surface elements of the structured-light-emitting array and the elements in the receiver array are at least approximately imaged in the same plane in a part of the object area. The electronically controlled movement of the light-emitting surface elements to a different location can be carried out by micromechanical means. Electronically controlled movement is also possible. The mean object point brightness and the color information can also be obtained from the signal profile, by using a color camera.

(0021) A method for 3D recording is also proposed, in which a light-emitting surface element is in each case preferably positioned on each B-path BS_{Aj} in the time intervals Δt_i for the detection of light. The B-paths BS_{Aj} are in this case directed at the pupil center PZ_{OA} of the imaging objective in the array area, so that the convergence point K_1 is positioned at least approximately at the pupil center of the imaging objective. Furthermore, the convergence point K_1 is also positioned in the pupil plane of the illumination objective, and a respective image of a receiver element and a respective image of a light-emitting surface element are thus positioned in the object area at least approximately jointly on the image of a B-path BS_{Aj} during the movement process. A pair with a fixed association can thus in each case be formed in the object area from the image of a receiver element and the image of a light-emitting surface element, and the respective image of a receiver element and a respective image

of a light-emitting surface element can be made to coincide at least approximately once in the object area during the movement process of the light-emitting surface elements. This includes the situation where there are two central-perspective objectives with coincident main planes. In this case, the receiver array may be fixed, and may be set such that the focus region "passing through" or the focus plane of the illumination objective coincides with the focus plane of the imaging objective at least once. It is advantageous if the focus plane of the illumination objective, as it "passes through" always remains in the comparatively large depth of focus range of the imaging objective. This approach can be achieved using electronic gratings with a very large number of pixels. Electronic gratings may be expanded or compressed continuously during the movement process, in order to satisfy the condition for convergence of the path loci.

(0022) In addition, a method for 3D recording of object surfaces in a scene is proposed, in which a light-emitting surface element is in each case preferably positioned on a respective B-path BS_{Aj} with an at least approximately constant relative light intensity, at least at a time t_i within each time interval Δt_i, in the time intervals Δt_i for the detection of light. In this case, the convergence point K_1 is positioned at least approximately in the focal plane of the illumination objective in the object area and, additionally, at the pupil center PZ_{OA} of the pupil of an imaging objective in the object area. During the movement process, a respective image of a receiver element and a respective image of a light-emitting surface element in the object area are positioned at least approximately jointly on the image of a B-path BS_{Aj}, at least at a time t_i within each time interval Δt_i for detection, and hence, at least at this time t_i, a pair with a fixed association is in each case formed in the object area from the image of a receiver element and the image of a light-emitting

surface element, and pairs with a fixed association are thus produced in the object area. The B-paths BS_{Aj} are in this case positioned parallel to a straight line g_{AP}, with the straight line g_{AP} intersecting the focal point F_{AB} of the illumination objective in the array area, and having the gradient whose magnitude is the quotient of the "distance between the pupil center PZ_{OA} of the pupil of the imaging objective in the object area from the axis of the illumination objective and the focal length f_B of the illumination objective", with this gradient of the straight line g_{AP} being related to the axis of the illumination objective. Two central-perspective objectives with mutually inclined axes may be used. The receiver array can preferably be fixed and set such that the focus plane of the illumination objective which only "passes through" coincides at least once with the focus plane of the imaging objective. An at least approximately linear relative movement of the receiver array with respect to the imaging objective is carried out parallel to the optical axis of the imaging objective and, during the movement process, signal values are read from each receiver element a number of times successively so that a signal profile is in each case formed by means of a receiver element and, during the image of a number of movement paths produced in this way for elements in the receiver array using the imaging objective, at least one path locus SB_2 with a convergence point K_2 at the focal point F_{OA} of the imaging objective is at least approximately formed from their images in the object area. The receiver array is moved such that a respective image of a receiver element and a respective image of a light-emitting surface element in the object area are made to coincide, and are moved, at least approximately jointly on the image of a B-path BS_{Aj} at least at a time t_i within each time interval Δt_i during the movement process, and pairs of images are thus produced in the object area. Since each element of the receiver array allows a signal profile to

be obtained, this allows parallel processing to be used. Furthermore, the imaging objective may also be moved with respect to the receiver array.

(0023) Furthermore, a method for 3D recording of object surfaces in a scene is proposed, in which the convergence point K_1 of the path locus SB_1 is made to coincide at least approximately, together with the convergence point K_2 of the path locus SB_2 in the object area, both with the focal point F_{OA} and with the pupil center PZ_{OA} of the pupil of the imaging objective, with the illumination objective and the imaging objective each being designed to be at least approximately telecentric on the array side. The light-emitting surface elements are moved on paths at least approximately parallel to a straight line g_A. The straight line g_A passes through the focal point F_{AB} of the illumination objective in the array area. The gradient of the straight line g_A is provided by the magnitude of the quotient "focal length of the illumination objective and the distance d of the focal point F_{AA} of the imaging objective from the axis of the illumination objective in the object area", with this gradient of the straight line g_A being related to the straight line at right angles to the axis of the illumination objective and, in this case, the straight line g_A coincides with the straight line g_{AP} owing to the telecentric nature of the imaging objective in the array area. This method allows 3D recording over a very large depth of focus range, in which case an arrangement having parallel objectives, which are at least approximately physically identical, can advantageously be chosen. The structured lighting is preferably produced by an illuminated line grating. The receiver array is moved in a straight line parallel to the optical axis of the imaging objective. Each element in the receiver array thus has its own movement path. When these movement paths are imaged using the imaging objective, the images of these movement paths produce a second

path locus with a convergence point K_2 of the imaged paths in the object area at the focal point F_{OA} of the imaging objective. Furthermore, the convergence point K_1 and the focal point F_{OA} of the imaging objective can be made to coincide, at least approximately, in the object area. In this case, the convergence point K_1 of the paths in the object area is formed by locations of specific relative light intensity of the illuminated line grating, for example the maximum of the transmission of the line grating, being moved on movement paths at least approximately parallel to a straight line g_A. In this method, periodic signals with a modulation maximum can be detected in the elements in the receiver array, from which the information about the absolute phase of an object point can be attained, in conjunction with the arrangement. If the illuminated line grating is moved at a constant speed, periodic signals at a constant frequency can be obtained in the elements of the structured-light-emitting array. This simplifies signal evaluation, and can therefore lead to a considerable reduction in the computation time. The sharp-image areas are made to coincide by synchronous control of the structured-light-emitting array and of the receiver array.

(0024) The position of the at least one light-emitting surface element may also be fixed and, in this case, at least components of the illumination objective are moved.

(0025) Furthermore, a method for 3D recording of object surfaces in a scene is proposed, in which one light-emitting surface element is in each case preferably arranged at least approximately at each suitable location O_{ABj} in the structured-light-emitting array relative to the illumination objective in a time period Δt_B in the time intervals Δt_i for the detection of light, and is actuated such that it emits light, and is imaged by the illumination objective, and this light-emitting surface element is always imaged at a predetermined location in the object area O_{OBj}, at least at a time t_i within the time

interval Δt_i. This image location O_{OBj} of a respective light-emitting surface element is changed by actuation in the object area by actuating another respective predetermined surface element and causing it to emit light, so that the image of each light-emitting surface element is moved through the object area on a controllable path curve, structured from distance increments AI_O of the images of the distances AI_A of the light-emitting surface elements in the array area - in the sense of moving in a controlled manner to predetermined, different positions. In each position after the movement process - by an integer n, including n = 1, of the distance increments AI_O - at least one signal value is detected from a receiver element and is read, and a signal profile is thus formed from a number of processes of detection and reading of elements in the receiver array. The location of the detected and read element in the receiver array is thus changed continuously. The locations of the detected and read elements in the receiver array lie at locations O_{AAj} in the receiver array, and the image of this location O_{AAj}, the image location O_{OAj}, is optically conjugated in the object area with the predetermined image location O_{OBj} of the light-emitting surface element. A respective image of a detected and read element in the receiver array is thus made to coincide in the object area with the image of a respective light-emitting surface element, at least at a time t_i within the time interval Δt_i, and a pair of images with alternating images is thus produced in each case, which gradually assumes different positions in the object area. Such pairs thus gradually pass through the object area in depth. In the process, sharp-image volumes of the image of each light-emitting surface element in each case coincide with a surface element of the object surface at least once in the time period Δt_B in one time interval, and the detected and the read elements in the receiver array have a

signal profile with at least one relative extreme of the signal magnitude in the time interval Δt_i of coincidence, with the time period Δt_B being made greater than the time interval Δt_i, and at least one time interval Δt_i thus being matched in time to the time period Δt_B.

(0026) This method can be carried out without any movement of an array, that is to say completely electronically. The structured-light-emitting array and the receiver array may be rigid, preferably three-dimensional structures, and, for example, the light-emitting array may have light-emitting diodes or vertically emitting laser diodes in a 3D arrangement. Individual surface elements are actuated electronically, and are caused to emit light, gradually. The actuation of predetermined light-emitting surface elements and the reading of elements of a receiver array, with their images representing an image pair in the object area, result in the signal value of an element in the receiver array reaching a maximum precisely with the image pair corresponds at least approximately to an element of the object surface. Due to its fixed position in conjunction with the structure-light-emitting array and due to the parameters of its imaging in the object area, a light-emitting surface element represents a small volume element. The reading of only that element in a receiver array which has an image in the object area which is at least approximately optically conjugated with the image of the light-emitting surface element results in a check for the presence of an element of the object surface in this volume element. Furthermore, the distance increments which are associated with the images of the light-emitting surface elements preferably form paths in the object area in a straight line, which are associated with a path locus SB_1 with a convergence center K_1. This results in unique signal recovery, since the paths of the path locus SB_1 do not

crossover in the object area. If a priori knowledge of the object surface is available, individual subsections can be composed from distance increments. The actual movement of a light-emitting surface element can thus be simulated by actuating different light-emitting surface elements. In principle, the mechanical configuration of the light-emitting array can represent a 3D model of the object surface to be investigated, and the light-emitting surface elements are imaged at the same time on the object surface. This also applies in an analogous manner to the structure of the receiver array. This may also have an object-matched 3D structure. Both the light-emitting array and the receiver array may have a number of surfaces in the depth direction with light-emitting elements, preferably receiving elements, so that it is possible to record three-dimensional objects with a large depth extent, without any mechanical movement. Unknown object surfaces in a defined measurement volume can thus be recorded.

(0027) Furthermore, a method for 3D recording of object surfaces in a scene is proposed in which a line of symmetry is preferably formed by object surfaces, which are illuminated by a radiation source, with a first and at least one second imaging beam path between the two axes of two imaging objectives for imaging of the object surfaces. Each imaging beam path has at least one associated receiver array, and the two receiver arrays each have elements which detect light from the elements of the illuminated object surfaces in the object area in the time period Δt_B during the recording process, and the two receiver arrays are each moved to a different location during the recording process. The light from the elements of the object surfaces is detected at least approximately simultaneously for the duration of a time interval Δt_i by the elements in the receiver array, and the elements in the receiver array are then read, with signal values being

obtained in each case. The object surfaces are preferably illuminated in the foreground, and the background of that part of the scene which is further away may also be illuminated. During the recording process, the two receiver arrays are moved at the same time on movement paths AS_{A1} and AS_{A2}. The images of the movement paths AS_{A1} and AS_{A2}, the paths AS_{O1} and AS_{O2}, are positioned at least approximately on the line of symmetry between the two axes of the objectives in the object area. A convergence point K_{21} is formed from the path locus SB_{21} of the images of the movement paths AS_{A1j} of the individual elements in the first receiver array, the paths AS_{O1j}, a convergence point K_{22} is formed from the path locus SB_{22} of the images of the movement paths AS_{2j} of the individual elements in the second receiver array, the paths AS_{O2j}, and the convergence point K_{12} and the convergence point K_{22} are made to coincide on the line of symmetry, and form a convergence point K_0 on the line of symmetry, and the two receiver arrays are moved such that their images at least partially coincide in the object area, so that the images of the elements in the first receiver array and the images of the elements in the second receiver array are made to coincide at least approximately in pairs in the object area, with those elements of the two receiver arrays which form pairs each representing corresponding elements. A current coincident point is thus preferably formed in each case from two images of elements, and is moved through the object area. This is preferably done with all the elements in the receiver arrays. Signal profiles S_1 of the first receiver array are preferably formed by reading the elements during the movement of the first receiver array. The first receiver array is moved parallel to a straight line g_{A1P}, and the elements in the first receiver array are thus moved at least approximately parallel to a straight line g_{A1P} on movement paths AS_{A1j}. Signal profiles S_2 of the second receiver array are also formed by reading the elements during the

movement of the second receiver array, and the second receiver array is moved parallel to a straight line g_{A2P}, and the elements in the second receiver array are thus moved at least approximately parallel to a straight line g_{A2P} on movement paths AS_{A2j}, with the second receiver array being moved at least approximately at the same time as the first receiver array. The straight line g_{A1P} is caused to intersect at a point P_{A1} on the line of symmetry in the main plane of the first imaging objective in the array area, and the straight line g_{A2P} is made to intersect at a point P_{A2} on the line of symmetry in the main plane of the second imaging objective, with the straight line g_{A1P} additionally including the focal point F_{A1} of the first imaging objective, and the straight line g_{A2P} including the focal point F_{A2} of the imaging objective in the array area. The signal profiles S_{1j} and S_{2j} recorded in each element of the receiver array are modulated to a lesser or greater extent owing to the natural structuring of the illuminated object surface, or else the self-luminescent object surface. This modulation, which occurs especially on the sharply imaged elements of the object surface, is intended to be evaluated to determine the z_O position of the respectively associated elements of the object surface. The two signal profiles S_{1j} and S_{2j} of two corresponding elements 1j and 2j in the receiver arrays are stored in the memory of a computer over the path of the movement of the two receiver arrays. In this case, the only elements of two receiver arrays which represent corresponding elements are those whose images coincide at least at one time in a sharp-image volume in the object area. An element in the first receiver array and an element in the second receiver array thus form a pair of corresponding elements at at least one time in a common sharp-image volume. Superimposed signal pieces $S_{1\ part\ j}$ and $S_{2\ part\ j}$ are now formed from the windows in each of the two signal profiles S_{1j} and S_{2j} from each of the two signal profiles S_{1j}

and S_{2j} by means of a window function with at least one single window, with a minimum window length corresponding to two signal values and a maximum window length which corresponds at least approximately to the length of the signal profiles S_{1j} and S_{2j}. Window lengths with a length of, for example, 8 or 16 signal values are advantageous. This window function is moved synchronously through at least one signal value, which corresponds to an increment in the movement of the receiver array, over each of these two signal profiles S_{1j} and S_{2j}, and a signal piece $S_{1\ part\ position\ k\ j}$ and $S_{2\ part\ position\ k\ j}$ is in each case formed from each current window at the position k, where $1 \leq k \leq m$. In this case, these successively formed signal pieces $S_{1\ part\ j\ position\ k\ j}$ and $S_{2\ part\ j\ position\ k\ j}$ are superimposed in each of the two signal profiles S_{1j} and S_{2j} in one subregion, with the movement of the window function in the two signal pieces in each case being started at the same end of the two signal profiles, S_{1j} and S_{2j}. The crosscorrelation function is then calculated, in each case starting from two signal pieces at the position 1 $S_{1\ part\ position\ 1\ j}$ and $S_{2\ part\ position\ 1\ j}$, but with one of the two signal pieces being inverted in advanced, that is to say all the values in it are mirrored, and the maximum of the crosscorrelation function $MCC_{1\ 2\ j\ position\ 1}$ is thus calculated from an original signal piece $S_{1\ part\ position\ 1\ j}$ and from an inverted signal piece $S_{2\ part\ position\ 1\ INV\ j}$, and is stored. The inversion is necessary in order to obtain signals which can be correlated, since the imaging beams of the elements of a corresponding pair move in opposite directions along a track, that is to say, for example, toward one another, in the object area in an at least approximately identical section of the scene during the movement process. In this case, this track lies parallel to the main section of the 3D recording arrangement. After calculating the maximum of the crosscorrelation function $MCC_{1\ 2\ j\ position\ 1}$ at the position 1, the window function is moved into the position 2, so that the

maximum of the crosscorrelation function $MCC_{1\,2\,j\ position\ 2}$ is calculated in the described manner for the two next signal pieces, until the window function arrives at the position m of the other end of the two signal profiles S_{1j} and S_{2j}, and the maximum $MCC_{1\,2\,j\ position\ m}$ of the crosscorrelation function $MCC_{1\,2\,j\ position\ m}$ is thus once again determined. A maximum value curve is formed from the m calculated maxima MCC_m, with the resultant maximum $M_{m\,j}$ once again being determined on this maximum value curve, and the location of the maximum $M_{m\,j}$ on the maximum value curve being associated with the two original signal profiles, and hence with the path of the movement of the two receiver arrays. This maximum value curve, calculated in this way, may have the profile of a Gaussian function. In order to prevent errors, an intensity threshold may be used, by which means signal pieces with a very low mean intensity are excluded from the further processing. The location of the respective maximum M_j is thus defined as the location of the image of the respective element of the object surface associated with the two corresponding elements 1j and 2j in the array area. The z_O coordinate of the respective element of the object surface in the z_O direction is calculated from the location of this maximum M_j in the array area, and the x_O and y_O positions of the respective elements of an object surface are also calculated in this way, since the geometry of the 3D recording arrangement is known. The positions of those elements of an object surface from which signal profiles have been recorded can thus be calculated, with the geometry of the 3D recording arrangement being known and the movements, including the step width of the movement, of the two receiver arrays being predetermined.

Furthermore, the axis of a first imaging objective for the imaging of the object surfaces may be aligned parallel to the axis of a second imaging objective for imaging the object surfaces. It is possible for the main plane of the first imaging objective in the array area and the main plane of the second imaging objective to coincide at least approximately in a common plane, and for the receiver arrays to be at least approximately located jointly in one plane. This means that the point P_{A1} lies on the line of symmetry and the point P_{A2} lies on the line of symmetry, so that the two points P_{A1} and P_{A2} are made to coincide, at least approximately, at a point P_A. The 3D point cloud can thus be obtained from free-space scenes, even in the background of the scene.

(0028) Furthermore, a method for 3D recording of object surfaces in a scene is proposed, in which illuminated object surfaces are preferably imaged using a first and at least one second imaging beam path. During the recording process, the two receiver arrays are moved simultaneously and parallel to the respective optical axes of the parallel imaging beam paths, which are at least approximately physically identical and whose main planes coincide, with the object surfaces in the scene being illuminated. The signal profile S_{1z} is formed by reading elements in the first receiver array which lie laterally alongside one another during the movement of the first receiver array, such that the only elements in the receiver array which are in each case used for signal formation are those which lie on paths which are aligned parallel to a straight line g_{A1P}, which intersects the point P_A in the common main plane of the imaging objectives. The signal profile which is formed thus corresponds to at least approximately to the signal profile S_1 which is obtained in the case of an actual movement parallel to a straight line g_{A1P} and the signal profile S_{2z} is formed by reading elements in the second receiver array which are located laterally alongside

one another during the movement of the second receiver array, so that the only elements in the receiver array which are in each case used for signal formation are those which lie on paths which are aligned parallel to a straight line g_{A2P}, which intersects the point P_A in the common main plane of the imaging objectives. The signal profile S_{2z} which is formed thus corresponds at least approximately to the signal S_2 which is obtained in the case of an actual movement parallel to a straight line g_{AP2}. A current coincidence point of elements in the two receiver arrays is thus in each case formed at least at a time t_i in a time interval Δt_1, and this coincidence point is in each case formed successively at different predetermined locations in the object area in the time Δt_B.

(0029) The z_O coordinate of the respective element of the object surface is calculated from the two signal profiles S_{1j}, S_{2j} of two elements, which each correspond at least at one time, in the receiver array, by means of the correlation method already described above, with two windowed signal profiles and with the respective piece-by-piece inversion of signal pieces to determine the z_O position of an element of the object surface, and their x_O and y_O positions are thus also calculated, with the entire 3D point cloud of object surfaces in a scene being calculated, with the geometry of the 3D recording arrangement being known and the movements of the receiver arrays being predetermined.

(0030) The imaging objective may also be moved with respect to the receiver array.

(0031) Furthermore, a method for 3D recording of object surfaces in a scene using at least one electromagnetic radiation source is proposed, which is in the form of a structured-light-emitting array with regions of different light intensity. In addition, at least one radiation source is preferably formed by means of at least one structured array as

a structured-light-emitting array with light-emitting surface elements. In this case, a structured array may preferably also be used in the form of a line grating with a radiation source arranged in front of it. Furthermore, an electronically controllable line grating may be configured in the array area. The radiation source and the structured array together form the structured-light-emitting array. The locations of specific relative light intensity of the structured-light-emitting array as well as those of the local extremes of the light intensity of this structured-light-emitting array can be made to move electronically. The radiation source may be designed for radiation in the visible and in the invisible spectral bounds, for example in the spectral band from 750 nm to 900 nm. Furthermore, at least one illumination beam path having at least one illumination objective is arranged. The illumination objective is associated with the structured-light-emitting array. However, an image of the structured-light-emitting array may also be associated with the illumination objective for imaging. In this case, the illumination objective has an effective aperture stop with an extent D_B and an aperture center BZ_B. The structured-light-emitting array and the illumination objective are used for structured illumination of the object surfaces in the scene. Furthermore, at least one imaging beam path is arranged with at least one imaging stage for the imaging of the elements of the object surfaces in the scene. This imaging objective has at least one associated receiver array. The imaging objective has an effective aperture stop with an aperture center BZ_A for imaging the elements of the object surfaces. This imaging objective has at least one associated receiver array with elements which, during the recording process, detect light from the elements of the structured-illuminated object surfaces in the object area. In this case, the distance d of the pupil center PZ_{OB} of the illumination objective, as the

image of the aperture center BZ_B in the object area, from the pupil center PZ_{OA} of the imaging objective, as the image of the aperture center BZ_A in the object area, is at least one eighth of the extent D_B of the aperture stop of the illumination objective. In this case, an image of a light-emitting surface element in the object area is formed from a light-emitting surface element in a light intensity distribution with a relative light intensity, which is preferably predetermined to be at least approximately constant, by imaging using the illumination objective. Furthermore, a movement system preferably having at least one moving component is arranged, and is associated with the structured-light-emitting array. The movement paths of the light-emitting surface elements in the array area are preferably formed from the mechanical movement of the structured-light-emitting array. However, it is also possible for the light-emitting surface elements to be moved electronically, for example in the lateral direction, at the same time, and for the movement system, which has at least one moving component, to provide for the structured-light-emitting array to be moved parallel to the optical axis of the illumination objective. Once these movement paths have been imaged by the illumination objective in the object area, their image is formed at least approximately as a path locus SB_1 with a convergence point K_1.

(0032) Furthermore, in an arrangement for 3D recording of object surfaces in a scene, the movement paths of the light-emitting surface elements may be arranged at least approximately parallel, with the convergence point K_1 thus being positioned at least approximately in the focal plane of the illumination objective in the object area, and at the pupil center of the imaging objective in the object area.

(0033) Furthermore, in an arrangement for 3D recording of object surfaces in a scene, the light-emitting array may be an electronically controllable line grating in which the

position of the lines and the line width are controllable. In this case, the lines may be arranged at right angles to the main section, and the movement paths of the light-emitting surface elements, and hence also of the light-emitting surface elements with local extremes of the light intensity in the array area - as a result of the mechanical movement of the structured-light-emitting array and of the electronic control of the structured-light-emitting array are formed in the array area. At least one path locus with a convergence point K_1 can be formed at least approximately from these movement paths in the array area in the main section and in each section plane parallel to the main section. The convergence point K_1 of the path locus may be arranged at the pupil center PZ_{AA} of the imaging objective in the array area.

(0034) Furthermore, in an arrangement for 3D recording of object surfaces in a scene, the movement paths of the light-emitting surface elements may be arranged at least approximately parallel to a defined straight line g_{AP}. In this case, the light-emitting surface elements preferably have a relative light intensity which is predetermined to be at least approximately constant in a light density distribution. The straight line g_{AP} intersects the focal point F_{AB} of the illumination objective in the array area and the magnitude of its gradient is the quotient of the "distance between the pupil center PZ_{OA} of the pupil of the imaging objective in the object area from the axis of the illumination objective and focal length f_B of the illumination objective", with this gradient of the straight line g_{AP} being related to the axis of the illumination objective.

(0035) Furthermore, in an arrangement for 3D recording of object surfaces in a scene, one component of the movement system may be associated with the receiver array and hence movement paths AS_{Aj} on parallel straight lines are associated during the mechanical movement of the receiver array on a

movement path of its elements, with at least one path locus SB_2 with a convergence point K_2 in the object area in this case being formed at least approximately from the images AS_{0j} of the paths AS_{Aj} for imaging by the imaging objective. The convergence point K_1 and the convergence point K_2 can be made to coincide at least approximately in the object area with the focal point F_{OA} and the pupil center PZ_{OA} of the pupil of the imaging objective. Furthermore, the imaging objects can be designed to be telecentric on the side of the area of the array.

(0036) Furthermore, in an arrangement for 3D recording of object surfaces in a scene, one component of the movement system can be associated with the receiver array and hence movement paths AS_{Aj} on parallel straight lines are associated during the mechanical movement of the receiver array on a movement path of its elements, with at least one path locus SB_2 with a convergence point K_2 in the object area, being formed at least approximately from the images of these paths for imaging by the imaging objective. The convergence point K_1 and the convergence point K_2 can be made to coincide at least approximately in the object area with the focal point F_{OA} and the pupil center PZ_{OA} of the pupil of the imaging objective, and the illumination objective and the imaging objective each being designed to be telecentric on the side of the area of the arrays. The axes of the illumination objective and of the imaging objective are thus arranged parallel to one another, and their focal planes can be made to coincide in the object area. Furthermore, in an arrangement for 3D recording of object surfaces in a scene, the components of the movement system can be arranged such that, in the array area, an overall movement direction is provided at least approximately parallel to a straight line g_A in the array area, with the focal point F_{AB} of the illumination objective as the reference point for the light-emitting array, so that the elements of

the structured-light-emitting array move on straight lines which are parallel to the straight line g_A, and this straight line g_A is made to intersect the focal point F_{AB} of the illumination objective in the array area and the gradient being provided by the magnitude of the quotient "focal length f_B of the illumination objective and the distance d of the focal point F_{AA} of the imaging objective from the axis of the illumination objective in the object area", with this gradient of the straight line g_A being related to a straight line at right angles to the axis of the illumination objective.

(0037) Furthermore, in an arrangement for 3D recording of object surfaces in a scene, the structured array may be formed at least on one partial region of a disk, which preferably has an associated rotating precision bearing with a shaft having a rotating motor, so that a rotating disk is formed.

(0038) Furthermore, in an arrangement for 3D recording of object surfaces in a scene, the rotating disk has transparent plate sectors of different geometric-optical thickness.

(0039) Furthermore, in an arrangement for 3D recording of at least one object surface in at least one scene, the receiver array may be a color camera.

(0040) In addition, it is possible to use a special receiver array with RGB channels and a fourth channel, the NIR channel, for example with a wavelength interval of 750 nm to 900 nm, for obtaining information for the 3D point cloud.

(0041) Furthermore, in an arrangement for 3D recording of at least one object surface in at least one scene using at least one electromagnetic radiation source, the radiation source is formed by means of at least one structured array as a structured-light-emitting ray with light-emitting surface elements. There is at least one illumination beam path with at least one illumination objective, which has an effective

aperture stop with an extent D_B and an aperture center BZ_B, for structured illumination of the object surfaces in the object area. The illumination objective is associated with the structured-light-emitting array, including an image of it. In addition, the at least one illumination beam path has an associated imaging beam path with at least one imaging stage for the at least one object surfaces with at least one imaging objective, which is associated with the receiver array or an image thereof, for imaging of the elements of the object surfaces, and which has an effective aperture stop with an aperture center BZ_A. A receiver array is used during the recording process to detect electromagnetic radiation from the elements of the illuminating object surfaces in the object area. The distance d of the pupil center PZ_{OB} of the illumination objective, as the image of the aperture center BZ_B in the object area, from the pupil center PZ_{OA} of the imaging objective, as the image of the aperture center BZ_A in the object area, is at least one eighth of the extent D_B of the aperture stop of the illumination objective. The light-emitting surface elements have an at least approximately predetermined light intensity in a light intensity distribution, so that at least one image of a light-emitting surface element is formed in the object area by the imaging with the illumination objective. Thus, according to the invention, the sharp-image volume, in the object area, of at least one image of a light-emitting surface element in a structured-light-emitting ray - as a result of the predetermined association between the light-emitting surface element and the illumination objective and the association between the elements in the receiver array and the imaging objective, and the association between the illumination objective and the imaging objective in the 3D recording arrangement using Newton's imaging equation - is permanently matched to the sharp-image volume, which is represented by the

totality of the images of the elements in the receiver array in the object area.

(0042) In this case, the sharp-image volume which is produced by all the images of the elements of the receiver array in the beam propagation direction has at least one depth extent which is as large as the sharp-image volume of an individual image of a light-emitting surface element. In the object area, an image of one light-emitting surface element of a structured array is in each case associated in a fixed manner with at least one image of an element in the receiver array.

(0043) A structured-light-emitting array having a number of light-emitting surface elements arranged in a fixed manner in a three-dimensional structure can be formed from the data record of a known nominal object surface. After imaging of the surface elements by means of the illumination objective, images thereof are formed at various points in the object area. In the 3D recording arrangement, at least one element of a receiver array is in each case arranged at the optically conjugated locations in the array area of the imaging objective. For exact positioning of an object in the object area, which has elements of the object surface where an image of the light-emitting surface elements is located, the elements in the receiver array each detect a signal value above a threshold value. In this case, detection is carried out by the elements in the receiver array in parallel. This may be done at high speed.

(0044) Furthermore, in an arrangement for 3D recording of at least one object surface, the structured array may be a transparent microlens array, and the focal length and the axial position of the microlenses may be configured such that their foci are arranged on a 3D surface which at least approximately represents a surface which is optically conjugated with the nominal surface. The foci of the

microlenses at least approximately represent a number of optically conjugated locations of the nominal surface of an item being tested. The difference from a nominal position can thus be determined in order to determine the focus position in the image.

(0045) Furthermore, in an arrangement for 3D recording of at least one object surface, at least one relief with a three-dimensional structure having at least one period in the form of at least one ramp with at least one oblique ramp surface in the regression surface may be formed on the structured array. Light-emitting surface elements are preferably arranged as a binary coded pattern on the oblique ramp surface. These surface elements are formed by window surfaces, which are illuminated by the radiation source. The ramp surfaces are preferably inclined such that the regression line AG_{Aj} through the oblique ramp surface in the main section and after imaging by the illumination objective in the object area produces, as an image, a straight line AG_{Oj}, which points at least approximately at the pupil center PZ of the imaging objective. As a rule, there are a number of ramps, so that a straight line group with a convergence point K_1 is formed for a number of different regression lines AG_{Oj} from a number of different ramps, from their images, after they have been imaged by the illumination objective. The illumination objective in this case preferably has a large aperture. The convergence point K_1 is in this case made to coincide at least approximately at the pupil center PZ of the imaging objective. This means that, during the recording of images of the object surface, a ramp can be followed unambiguously at all depths, without this resulting in any problems with lateral mispositioning. The imaging objective may have a comparatively short focal length, shorter than that of the illumination objective, and is in this case masked out sufficiently to produce a large depth of focus range. The depth of focus range

of the imaging objective thus in this case governs the depth of focus of the 3D recording arrangement. The images of the ramps in the main section form a focus whose origin is located at the pupil center PZ. The ramp images thus pass through the object surface to be detected. A sharp image is in each case produced by the mask on the ramp surface at the intersection of a ramp image with the object surface.

(0046) Furthermore, in an arrangement for 3D recording of object surfaces in a scene having two imaging beam paths with two at least approximately physically identical imaging objectives which are arranged parallel, a first imaging objective and a second imaging objective, the main planes of the two imaging objectives are made to coincide, and each of them has a respective associated receiver array with detecting elements, so that a first and a second receiver array are arranged, and each have at least one associated movement system. The resultant movement of the first receiver array can in this case take place on a path AS_{A1} on the first upper branch of a letter Y, and the path AS_{A1} may lie parallel to the straight line g_{A1P} which, firstly, intersects the focal point of the first imaging objective in the array area and, secondly, intersects the point P_A at which the line of symmetry passes through the coincident main planes between the two optical axes of the two imaging objectives, so that the detecting elements in the first receiver array move on the path AS_{A1j}, with a part of the line of symmetry forming the lower part of the letter Y. The resultant movement of the second receiver array may take place on a path AS_{A2} on the second upper branch of the letter Y, and the path AS_{A1} may lie parallel to a straight line g_{A2P} which, firstly, intersects the focal point of the second imaging objective in the array area and, secondly, intersects the point P_A at which the line of symmetry passes through the coincident main planes between the two optical axes of the two imaging objectives. The detecting

elements in the second receiver array can thus move on the paths AS_{A1j}.

(0047) The scene may be a free space scene.

(0048) Furthermore, the resultant movement of the first receiver array may take place on a path parallel to the optical axis of the first imaging objective, and the only elements in the first receiver array which are read and are used to form a signal profile are those which are located on paths AS_{A1j} which lie parallel to a straight line g_{A1P} which, firstly, intersect the focal point of the first imaging objective in the array area and, secondly, intersect the point P_A at which the line of symmetry passes through the coincident main planes between the two optical axes of the two imaging objectives. Those elements in the first receiver array which are used for signal formation thus correspond to those which are located on paths AS_{A1j}, with a part of the line of symmetry forming the lower part of a letter Y, and the resultant movement direction of the second receiver array can take place on a path parallel to the optical axis of the second imaging objective, with the only elements in the second receiver array which are read and which are used to form a signal profile are those which are located on paths AS_{A2j} which lie parallel to a straight line g_{A2P} which, firstly, intersects the focal point of the second imaging objective in the array area and, secondly, intersects the point P_A at which the line of symmetry passes through the coincident main planes between the two optical axes of the two imaging objectives. Those elements in the second receiver array which are used for signal formation thus correspond to those which are located on paths AS_{A2j}.

(0049) Furthermore, in an arrangement for 3D recording of at least one object surface having two imaging beam paths with two at least approximately physically identical imaging objectives which are arranged parallel, a first imaging

objective and a second imaging objective, the main planes of the two imaging objectives are made to coincide at least approximately, and each of them is associated with a respective receiver array with detecting elements, so that a first and a second receiver array are arranged with elements, and the first and the second receiver arrays each have at least one receiver surface which is in each case at right angles to the main section. In this case, the receiver surface of the first receiver array preferably includes a path AS_{A1} which lies parallel to a straight line g_{A1P} on the first upper branch of a letter Y which, firstly, intersects the focal point of the first imaging objective in the array area and, secondly, intersects the point P_A at which the line of symmetry SL passes through the coincident main planes between the two optical axes of the two imaging objectives, so that the detecting elements in the first receiver array are arranged on the path AS_{A1} in the main section. In this case, a part of the line of symmetry SL preferably forms the lower part of the letter Y. At least one receiver surface in the second receiver array preferably lies on a path AS_2 on the second upper branch of the letter Y parallel to a straight line g_{A2P} which, firstly, intersects the focal point of the second imaging objective in the array area and, secondly, intersects the point P_A at which the line of symmetry SL passes through the coincident main planes between the two optical axes of the two imaging objectives, so that the detecting elements in the second receiver array are arranged on the path AS_1 in the main section. This arrangement allows the detection of illuminated elements of the object surface in the object area, on a plane at right angles to the main section. The receiver matrices are physically identical and are arranged in a position symmetrical with respect to the line of symmetry SL, and at the same height.

(0050) The procedure is preferably as follows: the

signals from the two receiver surfaces are preferably read line-by-line, so that the receiver surface of the first receiver array produces the signal profiles S_1 and the receiver surface of the second receiver array produces the signal profiles S_2. These signal profiles are evaluated line-by-line, with the lines at the same distance from the main section containing the respectively corresponding elements. In order to find the location of an element of the object surface in the object area, the evaluation is carried out using the already described correlation method, with two windowed signal profiles. In this case as well, signal pieces are produced by means of a window function. In this case, one signal piece is in each case inverted, by the signal values being mirrored. The crosscorrelation is in each case carried out between an original signal piece and a respective inverted signal piece, with the signal pieces each representing symmetrically arranged line details in the 3D arrangement, and a correlation coefficient in each case obtained and stored. In this case, the window of the window function, which may, for example, have a length of 64 pixels, is moved, for example, in steps by an increment which in this case corresponds to one pixel in the respective evaluated line. A larger window movement step than one pixel may also be used for overview measurements. The length of the window is chosen as a function of the relative aperture. In this case, the window length may also be variable. The z_O position of the elements of the object surface is thus determined in the line of symmetry SL, in a plane at right angles to the main section.

(0051) Furthermore, in an arrangement for 3D recording of at least one object surface, an illumination objective may have an associated first imaging objective with a receiver array and an associated second imaging objective with a receiver array, with the pupil center PZ_{OA} of the first imaging objective being arranged at a distance d from the pupil center

PZ_{OB} of the illumination objective. Each of the two imaging objectives has a respective associated three-dimensionally structured receiver array, so that a first and a second receiver array are arranged in the array area. In this case, the first and the second three-dimensionally structured receiver arrays each have at least two receiver surfaces on three-dimensionally separated surfaces, and the receiver surfaces of the first receiver array and the receiver surfaces of the second receiver array are each arranged such that pairs of optically conjugated images of at least parts of the receiver surfaces of the first receiver array, and of parts of the receiver surfaces of the second receiver array, are at least approximately formed in the object area. In this case as well, the evaluation is carried out using the correlation method with two windowed signal profiles, as already described above.

The invention will be described in the following text with reference, only by way of example, to the drawing, in which:

(0052) Figures 1 to 10 show various illustrations of the invention; and

Figures 11 to 15 show details which are important for understanding of the invention and its explanation.

(0053) The principles of the invention will be described first of all, with reference to Figures 11 to 15.

(0054) Figure 11 shows the illumination of an object having an object surface 200 through a lens 201, by means of a light source in the form of a pinhole diaphragm 202. The opening in the pinhole diaphragm 202 is arranged on the optical axis 203, which is shown by a dashed line, of the lens 201. Figures 11a, 11b and 11c differ in the distance between the pinhole diaphragm and the lens, as indicated by the paths A, B, C.

(0055) In Figure 11a, the distance A between the pinhole

diaphragm 202 and the main plane of the lens 201 is chosen such that the image point of the pinhole diaphragm 202 is located inside the object. Accordingly, the light cone which is projected into the object area from the pinhole diaphragm 202 is still comparatively extended on the object surface, as indicated by the area A'.

(0056) In Figure 11b, the distance between the pinhole diaphragm and the lens is chosen such that the pinhole diaphragm is imaged precisely on the object surface. The illuminated area on the object surface is very small. In Figure 11c, the distance between the pinhole diaphragm and the lens is sufficiently large that the light cone has its smallest extent even before the object surface, and it diverges again toward the object surface. The light spot size differs further, depending on the distance. It must now first of all be remembered that the image points for the situations in Figures 11a, 11b, 11c lie on a straight line, as indicated in Figure 11d. It should also be remembered that the different extent of the light cone in the situations in Figure 11a to 11c leads to a light intensity of different magnitude on the surface, and the illuminated spot accordingly appears to be relatively bright or less bright. This is symbolized in Figures 11a to 11c by the arrows, whose lengths represent the intensity of the light scattered in random directions on the surface. The maximum scattered light intensity occurs in Figure 11b. Figure 12 once again shows the relationship between the distance to the pinhole diaphragm, the light spot extent and the intensity of the scattered light.

(0057) With typical surfaces, the light is scattered diffusively from the surface of the object 200, so that it can be observed from different viewing directions. This is illustrated in Figure 13.

(0058) In principle, with the single light source such as a single pinhole diaphragm, it is now impossible to

determine the location of a particularly advantageous observation position. However, generally, an object is illuminated simultaneously from a large number of illumination points, for example by means of a grating mask or strip mask for shadowing a light source. This makes signal evaluation more difficult. This is because, although it is possible without any difficulties with a single pinhole diaphragm to determine the surface point simply by observing the signal intensity, further difficulties occur in the case of grating diaphragms or the like, since it is also necessary to identify the location of the respectively strongly light-emitting object region of a specific illumination point on the object.

(0059) The three-dimensional association is now typically carried out with a detector array, by evaluation of the signals obtained in this way. In order to simplify the association and evaluation, it is desirable for a specific region of the object surface to always fall on the same element of the detector array. To do this, the invention makes use of a further effect, which is known from optics and is illustrated with reference to Figure 14.

(0060) Figure 14a shows the illumination of the object surface (which in the illustrated situation, is located in the plane of the image) with a pinhole diaphragm whose aperture lies exactly on the optical axis 203. According to the arrangement of the pinhole diaphragm on the optical axis, the pinhole diaphragm image point which is projected onto the object also lies on the optical axis. If now, as is shown in Figure 14b, the pinhole diaphragm is moved laterally with respect to the optical axis, to be precise through a distance A, then the image point migrates correspondingly laterally on the surface through a distance A'. This is well known from geometric optics.

(0061) It can be seen that a superimposition of the movement from Figure 11 in the direction of the optical axis

and the movement from Figure 14 laterally with respect to the optical axis will result in the image point moving on a straight line which has a transverse component with respect to the optical axis, that is to say it is inclined with respect to the latter. The vectorial movement superimposition is shown in Figure 15.

(0062) In order to make it easier to identify the object region, the invention now proposes that an object point being observed by means of an observation system which lies exactly on the inclined image point straight line which is described by the migration of the image points through the object area. The important factor in the transition from diaphragms to gratings is now that light-emitting points which are located at different distances from the optical axis, for example apertures in a shadow diaphragm which are provided at different distances from the optical axis, result in image point straight lines with a different inclination in the object area for the same movement of a shadowing grating. This is illustrated with reference to Figure 15a. It can be shown that all these image point straight lines coincide at a single point, namely the confocal point, which lies on the focal plane of the imaging optics. The invention makes use of this knowledge by placing the pupil of the observation system at this point; the object surface regions can thus be observed exclusively along image point straight lines, as illustrated by Figure 15b, which simplifies the evaluation in the desired manner.

(0063) Figure 15c shows the signal response in an arrangement in which a single aperture is used for illumination, see Figure 11a. The graph shows the observed light intensity I plotted against the grating movement distance X. The sharp signal rise, which corresponds approximately to a delta function, results when the image point falls on the object surface, which thus scatters light

with a particularly high light intensity. If a number of light-intensity elements are superimposed, as in the case of a grating diaphragm, this in contrast results in a situation as shown in Figure 15d, where the intensity profile I on a specific pixel is illustrated cluttered against the movement X of the shadow grating, when the movement X has not only a component in the direction of the optical axis of the associated imaging system, but also a lateral component with respect to it. The graph shows that, although the delta function from 15c experiences changes in intensity, a significant signal peak still occurs, however, with light being focused onto the predetermined region of the surface. The object shape can still be evaluated in a simple manner taking account of the signal intensity on a single array element, that is to say pixel.

(0064) The rest of the discussion of embodiments relates to Figures 1 to 10. Figure 1 illustrates the arrangement and the method. A distinction is drawn between the array area and the object area. The following notation is used, the parameters and points in the array area have the letter A as the first index, and the parameters and points in the object area have the first index letter O. The second index item indicates the associated objective, that is to say if associated with the illumination objective 1, the letter B, and if associated with the imaging objective 2, the letter A. A line grating 3 with a grating constant p and a visible light radiation source arranged in front of it, that is to say a light source 4, are located in the array area. This light source 4 can be computer-controlled so that the mean illumination intensity is matched to the distance to the respective focus plane in accordance with the photometric law. The line grating 3 is associated with the illumination objective 1, with a telecentric beam path at right angles to the axis and extrafocally in the array area. The illumination

objective 1 images the line grating 3 in the object area, thus resulting in a structured illumination of the object area 5, at least at one time. For simplicity, the two main planes of the illumination objective 1, H_{AB} and H_{OB} are collocated in Figure 1. With this class of objectives, the two main planes are located well apart from one another. A receiver matrix 6 is associated with the imaging objective 6, which likewise has a telecentric beam path in the array area, at right angles to the axis and extrafocally in the array area. The imaging objective 2 images the object surface 5 in the array area. A single imaging beam A_{O1} is shown. For simplicity, the two main planes of the imaging objective 2, H_{AA} and H_{OA}, are likewise collocated in Figure 1. The illumination objective 1 and the imaging objective 2 are arranged with their optical axes parallel to one another, and with their optical axes separated by a distance d. The illumination objective 1 and the imaging objective 2 have the array-side focal points F_{AB} and F_{AA} and, in the object area, the focal points F_{OB} and F_{OA}. Owing to the telecentric configuration, the focal points F_{OB} and F_{OA} coincide with the outlet pupils PZ_{OB} and PZ_{OA} in the object area. Two illumination beams BLS_{O1} and BLS_{O2} and an imaging beam ABS_O are shown. The first linear guidance of the movement system, which is not shown here, is rigidly connected to the receiver matrix 6, and has a second, smaller linear guide, which is not shown here and is in turn fitted with the line grating 3. The first linear guide is connected to a high-precision length measurement system, which has a highly stable zero point. The movement axis of the first linear guide is parallel to the objective axes, and the measurement axis of the length measurement system is in this case parallel to the two objective axes. The movement direction of the second linear guide is at right angles to the objective axes. The line grating 3 on the second linear guide has an associated opposing grating, which is firmly connected to the first

linear guide and has illumination and receiver optics in the form of an incremental length measurement system. The evaluation electronics have an electronic interface to the computer, in order to provide the calculated movement of the line grating 3 as phase information close to real time in the computer. At the same time, a first reference structure is fitted on the line grating 3 in the part outside the image area that is used, and is optically scanned by a second reference structure, which is likewise fitted on the opposing grating. The two linear guides for the movement system start from the zero position. The movement direction of the first linear guide is aligned parallel to the optical axis of the imaging objective. The movement takes place toward the focal points. The smaller, second linear guide, which is fitted with the line grating 3, has an associated position control system, in order to make it possible to move the line grating at as constant a speed as possible and hence also at a constant phase rate. The nominal values for the position of the first linear guide are calculated from the current, absolute actual phase $\varphi_{grating}$ of the line grating 3, which is derived from a zero point. This is done in such a way that the locations of the same phase or the same relative light intensity on the line grating 3 move parallel to a straight line g_A, for example on the B-path BS_{A2}. The straight line g_A is defined such that it intersects the focal point F_{AB} of the illumination objective 1 and, furthermore, the main point H_{AA} of the imaging objective 2. The light-emitting surface elements are moved in array space on the B-paths BS_{Aj}. The images of these B-paths BS_{Aj}, including the B-paths BS_{A1} and BS_{A2} illustrated in Figure 1, are imaged in the object area. For example, the images BS_{O1} and BS_{O2} are formed from the B-paths BS_{A1} and BS_{A2}. The images BS_{O1} and BS_{O2} form a path locus SB_1 with the convergence point K_1, which coincides with the focal point F_{OA} of the imaging objective 2. Furthermore, the elements of the

receiver array are moved on paths AS_{Aj}. The illustration shows the paths AS_{A1} and AS_{A2}. Their images produce the path locus SB_2 in the object area, having the paths AS_{O1} and AS_{O2} with the convergence point K_2, which coincides with the convergence point K_1 at the focal point F_{OA} of the imaging objective 2, with the coincidence point of convergence point K_1 and of the convergence point K_2 generally being the coincidence point K_0. The planes of the object area, whose axes are mutually perpendicular, are successively only "moved through" this movement regime from the focus surface in that a strip pattern, which is imaged sharply by the illumination objective 1, can be observed in each of these planes when an object surface is present, and this strip pattern is imaged by the imaging objective 2 on the receiver matrix 2. This means that any sufficiently small object detail, in the object area, produces a modulated periodic signal in the associated pixel ij on the receiver matrix 6 when it is "recorded" by the sharp-image area, which signal contains the information about the absolute phase $\varphi_{Obj,ij}$ of the object point.

(0065) By way of example, Figure 2 shows the signal profiles S_O and S_R at an image point on the receiver matrix 6 with respect to the signal profile S_G, which can be detected on the line grating 3, by means of an imposing grating, during movement of the grating 3. The illustration shows the signal profile at the image point S_O of an object point, and the signal profile S_R at the image point of a reference point. In this case, the reference plate is located closer to the focal point F_{OB} than is the object surface. The relative phase φ_{RR} is calculated at the sampling point A_{PR} in the image point of a reference point in the region of the modulation maximum of the signal, and the relative phase φ_{RObj} is calculated at the sampling point A_{PO} in the image point of an object point in the region of the modulation maximum of the signal. The absolute

phase difference $\Delta\varphi_{grating}$ is calculated by means of the equation (3), and the absolute object phase φ_{Obj} is calculated using the equation (4), from which, using the equation (5), the Z_{OB} coordinate of each object point, namely Z_{Obj} is determined. The highly stable zero point N is used as the start point. Figure 3 shows a 3D recording arrangement having an illumination objective 1 and having an imaging objective 2, with both objectives having a beam path which is central-perspective on both sides in the array area, and thus having a small physical volume. The axes of the two objectives are inclined with respect to one another. The latter makes it possible to provide particularly high sensitivity to depth in a comparatively small measurement volume, for example for recording teeth for orthodontal work. The entire arrangement is accordingly miniaturized. The light originating from the light source 4 illuminates a line grating 3. This is moved on a path parallel to the straight line g_{AP} by means of a computer-controlled carriage, which is not illustrated here, on a linear guide and is projected by means of the illumination objective 1, with the pupil center PZ_{OB} onto the object surface 5. The straight line g_{AP} intersects the focal point F_{AB} of the illumination objective 1 in the array area, and intersects the main plane H_{AB} of the illumination objective 1 in the array area, at the point H_{ABG}. The image of the straight line g_{AP}, the straight line g_{OP}, lies parallel to the axis of the illumination objective 1, and, if extrapolated, intersects the main plane at the point H_{ABG}. The focal length of the illumination objective 1 is f_B. The object surface 5 is imaged by means of an imaging objective 2 on a receiver matrix 6, which is connected to a computer with Framegrabber with the computer evaluating the recorded images. The imaging objective 2 is arranged with respect to the illumination objection 1 such that the pupil center PZ_{OA} is located on the straight line g_{OP}. The pupil aperture of the illumination objective 1 is made

as large as possible, for example with an aperture ratio 1:2. This severely limits the depth of focus range in the object area. On the other hand, the pupil opening of the imaging objective 2 is made as small as possible, for example with an opening ratio 1:22. The depth of focus range in the object area is comparatively large. This is necessary since the receiver matrix 6 is arranged such that it is fixed. With regard to the measurement sequence: the line grating 3 is moved and the receiver matrix 6 is used to record images, for example 32. The movement of the grating 3 with the grid constant p is measured with high precision to about 1% of the grating constant p. Images are recorded, with the phase change between two images generally being less than 2π, for example $3/2\pi$. The position of the receiver matrix 6, in which case a CMOS camera may be used owing to the wide dynamic range and the capability to evaluate individual pixels, is chosen such that the entire object area of interest can be recorded sharply. In this case, the receiver matrix 6 can also be rotated in accordance with the Scheimpflug condition, such that it contains the two points A_{A1} and A_{A2}. The 3D point cloud of the 3D measurement object is determined from the 32 recorded images, taking account of the geometry of the 3D recording arrangement and the imaging relationships. This is done by determining the absolute object phase φ_{Obj} for each object point. The z_{obj} coordinate is calculated from this, for each individual point. The x_{Obj} and y_{Obj} coordinates are calculated as a function of the z_{Obj} coordinate, via the imaging scale, from the known pixel pitch of the receiver matrix 6.

(0066) Figure 4 shows a 3D recording arrangement having an illumination objective 1 with a comparatively large pupil aperture, for example with an aperture ratio of 1:2.8 and a central-perspective beam path which is optimized for oblique

imaging. The illuminated area is located asymmetrically with respect to the axis of the illumination objective 1. Objectives in the medium focal length range are preferably used here, for example with focal lengths around 25 mm. The imaging objective 2 has, for example, an aperture ratio of 1:2.8 and has a telecentric beam path in the array area. The axes of the two objectives are arranged parallel to one another. The main planes of the illumination objective 1 and of the imaging objective 2 coincide at least approximately in the array area. The light originating from the light source 4 illuminates a reflection grating, for example an electronically controllable digital micromirror device 61. Furthermore, the electronically controllable digital micromirror device 61 and the receiver matrix 6 are rigidly connected to one another in the at least approximately identical plane in the array area. Both components are in this case located on a computer-controlled carriage on a linear guide. The movement direction of the carriage of this linear guide is aligned parallel to the axes of the two objectives, so that both components move synchronously and parallel to the optical axis of the illumination objective 1. The electronic actuation of the digital micromirror device 61 not only allows a light-emitting surface element 3A to be moved laterally, but also allows a light grating to be moved in accordance with a programmed pattern. A movement of a path BS_{Aj} parallel to the straight line g_{AP} can thus be produced for an individual light-emitting surface element 3A on the direct mirror device 61, as for the light-emitting elements, precisely matched to the movement by the computer-controlled carriage. The straight line g_{AP} intersects the focal point F_{AB} of the illumination objective 1 in the array area, and the main plane of the imaging objective 2 in the array area, at the main point H_{AA}. The image of the straight line g_{AP} in the object area, the straight line g_{OP}, lies on the axis of the imaging objective 2.

By way of example, the light-emitting surface element 3A is thus moved, as a light-emitting surface element with a constant relative light intensity, from the point B_{A1} to the point B_{A2}. In this case, the light-emitting surface element 3A may represent a maximum in an at least approximately $\cos^2$ light distribution, that is to say it may have the phase value 0 for detection of a signal. The light intensity distribution on the digital micromirror device 61 is projected by the illumination objective 1 onto the object surface 5. In this case, these straight lines, which are parallel to the straight line g_{AP}, and paths are imaged by the illumination objective 1, with the images of the movement paths BS_{Aj} of the light-emitting surface elements, that is to say in this case the light-emitting micromirrors of the digital micromirror device 61, form a path locus in the object area. By way of example, a light-emitting surface element 3A is moved on the movement path BS_{Aj}. The image of this movement path BS_{Aj}, points to the convergence point K_1 in the object area. The object surface 5 is imaged on a receiver matrix 6 by means of the imaging objective 2. The computer-controlled carriage, which is not illustrated here, of a linear guide is also fitted with the receiver matrix 6, and the pixels in the receiver matrix 6 are thus each moved on a path AS_{Aj} parallel to the optical axis of the imaging objective 2. The images of the paths AS_{Aj}, the paths AS_{Oj}, form a path locus in the object area with a convergence point K_2 at the focal point of the imaging objective, so that, with a telecentric imaging objective, the convergence points K_1 and K_2, the focal point F_{OA} and the pupil center PZ_{OA} coincide. An object point O in the object area is thus tracked by an image of a light-emitting surface element 3A in the depth direction of the object area during the movement process. Figure 4 shows the coincidence point $K_{Oj\,i}$ in the object area at that time, at the position $A_{O1}B_{O1}$ in the image of the light-emitting surface element 3A and of the

image of the element of the receiver array at the point A_{A1}, the image A_{O1}, at the time t_i. This element of the receiver array is moved on the path AS_{Aj}. Any offset of an element O on the object surface 5 from the coincidence point $A_{O1}B_{O1}$ at that time, in the direction of the imaging beam associated with that element in the receiver array, with respect to the time period of the recording Δt_i leads to a signal whose phase is Φ_{rS}. This results, for example, in $\Phi_{rS} = 2\pi \times \Delta x_A / p$ where p is the period of an at least approximate $\cos^2$ distribution, and Δx_A is the image of Δx_O as shown in Figure 4. If the object point O coincides with the coincidence point $K_{Oj\ i+1}$ at that time, for example at the position $A_{O2}B_{O2}$ at the time t_{i+1}, a signal is recorded whose phase is $\Phi_{rS} = 0$. The coincidence point at that time is moved further through the object area. A periodic signal can thus be recorded, which is attenuated by the increasing lack of focusing in the imaging. The width of the modulation curve of the periodic signal is governed by the ratio of the distance d between the optical axes and the diameter of the aperture stop D_B of the illumination objective. In order to allow zero-order strips to be uniquely identified, this ratio must generally not exceed a value of 10, with the sensible ratio also being governed essentially by the evaluation algorithm used for the signal profile. Figure 5 shows a 3D recorded arrangement for objects which are illuminated with structured light. In this case, the aim is to use the determination of the absolute phase of elements on the object surface to determine the point cloud thereof particularly quickly and accurately. To do this, a light source 4 illuminates a concentric grating 81, thus forming a structured-light-emitting array which is located on a planar surface, which is associated with a transparent plane-parallel plate 84, in a sector of a disk 83. There are a number of transparent segments with transparent plane-parallel plates 84

over the entire area of the disk 83. The concentric illuminated grating 81 is imaged by the illumination objective 1. The disk 83 is driven by a motor 85 at a rotation speed of, for example, 24 rpm. Furthermore, there are reference marks for identification of the center of a segment, and these are used for reading the receiver matrix 6. Furthermore, the information relating to the axial position of the disk 83 can be obtained in a planar region on the upper face of the disk 83, in the immediate vicinity of the concentric grating 81. The information obtained from the optical sensor head 87 about the radial position of the disk 83 is passed to a piezo controller 92, as a control voltage, in a control loop (which is not illustrated here) which has an electronically controllable voltage source for the piezo controller 92. In this case, the piezo controller 92 is connected to the receiver matrix 6 so that it is not actually the radial position which is kept constant here, but the distance between the concentric grating 81 and the receiver matrix 6. This thus results in a defined position being maintained between a light-emitting surface element and an element in the receiver matrix 6. The axial position of the associated structured-light-emitting region is kept in a constant position by a second piezo controller 93 in a control loop, with this second piezo controller 93 holding the disk 83 in the nominal position during rotation thereof. If precision bearings are used, there is generally no need to eliminate the axial displacement. Furthermore, a plane-parallel transparent compensation plate 94 is arranged after the imaging objective 2 in the imaging beam path, for axial compensation of the position of the receiver matrix 6. This means that the optical paths are the same for every angular position of the disk 83, that is to say in every segment associated with the light source and the receiver matrix 6, i.e. the object width for the structured-light-emitting array and the image width for

the receiver matrix 6 are the same. A sharply imaged strip pattern can thus in each case be observed on the object surface in the same plane in the object area, and this is also once again imaged sharply on the receiver matrix 6, via the imaging objective 1 and a transparent plane-parallel plate 95 with a specific optical thickness, since the focus plane of the imaging beam path lies in the same plane, due to the matching of the transparent plane-parallel plate 95. The rotation of the disk 83 results in transparent segments with a different geometric-optical thickness entering both the illumination beam path and the imaging beam path. The geometric-optical thicknesses are always matched such that the focus planes of the two beam paths coincide in the object area. The position of the focus planes in the object area varies from segment to segment, so that the entire object area is gradually only "focused-through" in depth, step-by-step. The position of the concentric grating changes in the radial direction from segment to segment. The phase is thus changed in a defined manner in steps on each segment change, for example in steps of 90°. The evaluation of a synchronization pulse in the edge region ensures that the receiver matrix detects an image only when the plane-parallel plate of defined thickness and with the concentric grating 81 is located with its entire area in front of the receiver surface. A periodic signal profile can thus be obtained in each element in the receiver matrix 6, with each signal value of the recorded signal profile being produced by means of another plane-parallel plate in another sector. In this case, the phase difference from one signal value to another is known with high precision owing to the optically read reference grating.

(0067) Figure 6 shows a 3D recording arrangement which is particularly highly suitable for mobile use, for example for computer-aided 3D orientation of robots in the close area, for gripping tasks. Furthermore, 3D handheld appliances for

recording objects in the close range below 1 m can be based on this arrangement. This 3D recording arrangement comprises an illumination objective 1 and an imaging objective 2, with both objectives having a central-perspective beam path in the array area, and a transparent profile grating 53, which may be regarded as a structured 3D array and is illuminated by a light source 4. This may represent a flashlight source with a flash frequency in time with the video. The transparent profile grating 53 has a number of ramps 54 and 56. As shown in Figure 8, a binary coded pattern, a bitmap, is located on the oblique ramp surfaces 55 of the ramp 54, with the directions of the ramp surfaces, or at least the associated regression lines in the main section, always pointing to the pupil center PZ of the imaging objective 2. The binary coded pattern is imaged at different depths in the object area. Figure 7 illustrates a further option for forming a ramp surface. The ramp surface 57 has a number of steps. A different binary coded pattern is in each case located on each step. The individual patterns are allocated the designations A_1, A_2, A_3 and A_4. The regression line through the ramp surface, the straight line AG_{Aj}, points to the pupil center PZ of the imaging objective 2. The ramp surface 55 on the transparent profile grating 53 on the ramp 54, in which case the former may be represented by a regression line AG_{Aj} in the main section, is imaged in the object area by means of the illumination objective 1. The illumination objective 1 is intended to have a large relative aperture, for example 1:.21. Furthermore, surface regions of the object surface are represented in possible positions at the same time in the images A_{10}, A_{20}, A_{30} and A_{40}, for illustration. A light-emitting surface element 3A is likewise imaged, and represents the image B_{FEL}. The sharp-image volume SV_{FEL} of the image B_{FEL} is illustrated. This is not very deep, owing to the large relative aperture ratio. In contrast, the imaging objective is

heavily masked. The elements in the receiver array are thus imaged with a considerably greater depth range. The image of the entire ramp surface is thus located in the sharp-image volume SV_{EE} of the associated element of the receiver matrix 6. If the illumination objective 1 has a large relative aperture, the image of a pattern disappears very quickly when the object is moved in depth. Ramp surfaces 54 can be arranged in a number of planes that are parallel to the main section on the transparent profile grating 53, each having a different mean object width, so that elements of an object surface 5 can be recorded at different depths in the object area, so that the depth recording range is particularly large.

(0068) Figure 9 shows an application for obtaining digital point clouds, which can be used for 3D television, for example for sports events, where the illumination level is good. However, the arrangement shown in Figure 9 can also be used for 3D recording in the amateur video field, and in photography. In order to produce an individual 3D photograph, a sequence of images is recorded by both receiver matrices 6 and 14. The receiver matrix 6 and the receiver matrix 14 are moved such that the focus range varies from image to image, until the entire depth of the object area has been covered. Natural light or artificial light, which generally has no three-dimensional structuring, is used for illumination in this case. The two receiver matrices 6 and 14 each have an associated first imaging objective 33 and a second imaging objective 2. The first imaging objective 33 and the second imaging objective 2 are telecentric in the array area, as a result of which the focal point F_{O1} and the pupil center PZ_{O1} coincide for the imaging objective 33. For the imaging objective 2, the focal point F_{O2} and the pupil center PZ_{O2} likewise coincide, owing to the telecentric configuration. The images of the straight lines parallel to the straight line g_{A1P}, and thus also the movement paths of the elements in the

receiver matrix 6 on these straight lines, are imaged by the imaging objective 33 in the object area, where they represent a path locus whose paths converge at the convergence point K_{21}, or a straight line locus with the intersection K_{21}, which also includes the straight line g_{O1P}. Furthermore, the images of the straight lines parallel to the straight line g_{A2P}, and hence also the movement paths of the elements of the receiver matrix 14, are imaged on this straight line by means of the imaging objective 2, thus resulting in a path locus in the object area whose paths converge at the convergence point K_{22}, and in a straight line locus whose intersection occurs at K_{22}. This straight line locus contains the straight line g_{O2P}, which coincides with the straight line g_{O1P}. The receiver matrix 6 and the receiver matrix 14 are moved such that the path loci with the convergence point K_{21} and the path loci with the convergence point K_{22} coincide jointly at the coincidence point K_O. There is thus one, and only one, corresponding element on the receiving matrix 14 for each element of the receiver matrix 6. The two receiver matrices 6 and 14 are each connected via an interface to at least one high-performance computer, which is in turn included in a high-performance communications network. The receiver matrices 6 and 14 are connected to a high-precision linear guide 20, which is in turn connected to a computer-controlled, high dynamic range linear motor 21. The two receiver matrices 6 and 14 are moved in the direction of the two focal points F_{A1} and F_{A2} in the z_A direction, so that the position of the common focus plane SCH i-1 changes in the object area. The objects 5, 18 and 19 are illuminated to a sufficient extent by a light source 15. The object 5 is first of all recorded at the point $P_{j\,i}$, which is located on the straight line $g_{O\,j\,1\,2\,P}$ which represents the location of the coincident straight lines $g_{O\,j\,1\,P}$ and $g_{O\,j\,2P}$, by the common focus plane SCH i. After this, for example only a few milliseconds later, the object surface 18 is recorded, for

example by the point $P_{K\ i+1}$ through the common focus plane SCH i+1 with an object point of the object surface 18 being located on the straight line $g_{O\ k\ 1\ 2\ P}$, to represent the location of the coincidence straight lines $g_{O\ k\ 1\ P}$ and $g_{O\ k\ 2\ P}$, at this time. The first points of the object surface 19 are recorded a few milliseconds later. The frequency shift of the movement of the two receiver matrices 6 and 14 is, for example, 24 Hz. The images recorded by the two receiver matrices 6 and 14 are evaluated such that signals are formed from elements which are located at least approximately at the same point on respective straight lines parallel to the straight lines g_{A1P} and g_{A2P}, for example on straight lines g_{Aj1P}, g_{Ak1P}, g_{Aj2P} or g_{Ak2P}, at the same time, that is to say which represent corresponding elements. As already described, correlation methods are used to calculate the z_O coordinates from the detected signals S_{1j} and S_{2j} for each pair of corresponding elements, and the entire point cloud of the object surface, or of the scene, is calculated from these coordinates, since the geometry of the arrangement and of the imaging scales is known via the z_O coordinate.

(0069) For moving objects, a point cloud is provided in time with the video. The information about the color of the respective object point is obtained, for example, from that receiver element which is located closest to the correlation maximum. The surface models of the objects or of the scene are calculated from the calculated point clouds. This requires a very high computation speed, although this can be achieved on the basis of special processors. It is possible to allocate a dedicated processor to each element in the receiver matrices 6 and 14. This is highly advantageous for carrying out the crosscorrelation process already described. Data reduction techniques may be used for transmitting the calculated data for 3D reproduction.

(0070) Figure 10 shows a 3D recording arrangement which

may be used, for example, for a multilevel obstruction sensor in daylight. Two imaging beam paths having two imaging objectives 33 and 2 are arranged, with the imaging objectives 33 and 2 each being designed to be telecentric in the array area. This is not absolutely essential, but results in design advantages. Each imaging objective 33 and 2 has a respectively associated three-dimensionally structured receiver array 106 and 114. These each have two receiver surfaces 107 and 108, as well as 109 and 110, and are arranged at right angles to the main section. Furthermore, these receiver surfaces 107 and 108, as well as 109 and 110, are respectively parallel to a straight line g_{A1P} and parallel to a straight line g_{A2P}. These straight lines g_{A1P} and g_{A2P} intersect the respective focal point F_{AA1} and F_{AA2} of the associated objective and the point P_A in the common main plane of the two imaging objectives 33 and 2. The images of the receiver surfaces 107 and 108, as well as 109 and 110, are imaged in the object area in accordance with the Scheimpflug condition, resulting in the coincidence of the two images of the receiver surfaces 107 and 109, as well as 108 and 110, of the three-dimensionally structured receiver array 106 and 114. Elements of an illuminated object surface 5 are imaged onto the four receiver surfaces 107 and 109, as well as 108 and 110. For example, the points O_1 and O_2 are imaged on the object surface. The correlation method, which has already been described in detail, may be used to determine the z_O position of the points O_1 and O_2 using the gray-scale or color distributions, when using color cameras the receiver matrices, from the surrounding area. This results in four signal profiles S_1 and S_2, as well as S_3 and S_4, respectively in the line of the associated receiver matrix in the main section via the respective line-by-line reading process, in each case starting, for example, at the A_A position, or at the B_A position, respectively. In this case, the associated, stationary elements of two respective receiver surfaces 107

and 108 or 108 or 110 each form a corresponding pair for each point in the object area on the two images, which are coincident in the object area, of the receiver surfaces 107 and 108, as well as 109 and 110.